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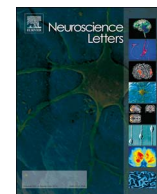
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Review article

Capacity and tendency: A neuroscientific framework for the study of emotion regulation

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ABSTRACT

It is widely accepted that the ability to effectively regulate one's emotions is a cornerstone of physical and mental health. As such, it should come as no surprise that the number of neuroimaging studies focused on emotion regulation and associated processes has increased exponentially in the past decade. To date, neuroimaging research on this topic has examined two distinct but complementary features of emotion regulation – the *capacity* to effectively utilize a strategy to regulate emotion and to a lesser extent, the *tendency* to choose to regulate. However, theoretical accounts of emotion regulation have only recently begun to distinguish capacity from tendency. In the present review, we provide a novel framework for conceptualizing these two intertwined, yet distinct, facets of emotion regulation. First we characterize brain regions that support emotion generation and are thus targeted by emotion regulation. Next, we synthesize findings from the dozens of neuroimaging studies that have examined emotion regulation capacity, focusing in particular on the most commonly studied emotion regulation strategy – reappraisal. Finally, we discuss emerging neuroimaging research examining state and trait regulatory tendencies. We conclude by integrating findings from neuroimaging research on emotion regulation capacity and tendency and suggest ways that this integrated model can inform basic and translational neuroscientific research on emotion regulation.

1. Introduction

Though emotions are generally adaptive, they can lead to mental and physical health problems if left unchecked [9,38,44,51,53,99]. Emotion regulation – the use of conscious or unconscious processes that change the nature, intensity or duration of one's emotions – is central to wellbeing [41,78].

Emotion regulation is driven jointly by one's *tendency* to choose a specific regulatory strategy and one's *capacity* to implement said strategy effectively [10,25,42,79]. Initial evidence suggests that regulatory tendency and capacity co-develop during childhood [71] and are related but not synonymous in adulthood [69]. While recent reviews have begun to characterize “different flavors” of emotion regulation by distinguishing between model-based and model-free or implicit and explicit forms of emotion regulation [11,32], prevailing models have not yet taken into account the complementary significance of regulatory capacity and tendency [25,78,82,93]. Here, we review existing neuroimaging findings related to the generation and regulation of emotion and then outline future directions for how regulatory capacity and tendency might be integrated in basic, developmental, and translational research.

2. Neuroimaging research on emotion regulation capacity and strategy

2.1. Emotion generation

Before considering how emotions are regulated, it is useful to consider how emotional responses are generated. For the purposes of this review, we define emotions as reasonably coherent combinations of affective experience, behavior and physiological activity that arise in response to motivationally-relevant stimuli [50,58,60,67]. Appraisal models suggest that emotions unfold in a series of steps that involve perceiving, attending to, interpreting and responding to an internal or external stimulus [6,92]. Importantly, such models also submit that emotions may be regulated at any point in the appraisal process [40,78]. In this framework, emotion generation and regulation rest on opposing ends of a continuum but rely on common psychological ingredients (e.g., controlling attention towards an emotional stimulus and interpreting its meaning) [43]. Here, we discuss neuroimaging data associated with emotion generation and emotion regulation separately for clarity's sake, but do not make strong claims about the extent to which neural circuits associated with these two processes are distinct

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versus overlapping.

Emotions emerge through top-down, cognitive processes or bottom-up, stimulus-driven processes via cortical-subcortical networks [16,55,64,81]. Importantly, no single neural circuit or set of neural computations can fully explain how emotions arise [64]. Here we focus on four brain regions that are most consistently implicated in emotion generation from a ‘model-agnostic’ perspective. The first of these is the amygdala, a subcortical structure whose functional significance remains a topic of ongoing debate. While many see the amygdala as being central to generating “core” affective responses [59,91], others have purported that amygdala activity flags the intensity [2], motivational salience [21] or ambiguity of affective stimuli [113]. Importantly, numerous neuroimaging meta-analyses and quantitative reviews have found that amygdala activity is attenuated by emotion regulation [12,24,68,93]. The insula, our second region, shares dense, bidirectional connections with the amygdala [3] and commonly co-activates with it in response to salient and negative stimuli [17,63], as part of a broader aversive processing network [48,88]. The insula’s structural and functional characteristics endow it with a unique capacity to integrate converging affective, cognitive and motor inputs and to motivate relevant behavior [17]. In contrast to the amygdala and insula, the medial prefrontal cortex (mPFC) is strongly associated with top-down representations of emotion [81] and supports both emotion generation and regulation [33,93]. Dorsal mPFC (dmPFC) and neighboring cingulate regions have been implicated in the generation and maintenance of learned fear responses [13,33,70], as well as the generation and regulation of negative emotion [12,81] and social cognition [1,23,83] – suggesting that dorsal mPFC aggregates cognitive, social and affective cues to form high-level representations of emotion. Ventral mPFC (vmPFC) integrates contextual, cue and memorial inputs to update affective judgments [22,90]. This is crucial for evaluating the affective significance of stimuli and contexts [2,46,63,65], and for maintaining representations of safety in the face of threat [30]. Given the roles that the amygdala, insula, and mPFC play in emotion generation, they are also necessarily involved in emotion regulation – as targets, intermediaries or perhaps even instigators of regulation.

2.2. Emotion regulation capacity

Emotion regulation capacity may be defined as the extent to which one is *capable* of using emotion regulation. Because the vast majority of neuroimaging research examining regulatory capacity has focused on reappraisal – or changing the way one thinks about an emotional stimulus so as to alter its import [40] – this review will concentrate on reappraisal as a paradigm case for what is presently known about emotion regulation capacity. Reappraisal capacity is typically assessed by instructing participants to reappraise and then evaluating changes in self-reported emotion relative to a control condition.

2.2.1. Neural systems supporting the capacity to reappraise

Reappraisal recruits prefrontal and parietal regions that support non-affective cognitive control processes such as response inhibition, task switching, and working memory [12,24,57,75,89,111,112]. Theoretical accounts of reappraisal have interpreted this as evidence that prefrontal and parietal executive control processes can be used to regulate affect much as they do non-affective impulses, thoughts and behaviors [78,79,82]. Consistent with this, transcranial magnetic stimulation (TMS) of the prefrontal cortex enhances cognitive reappraisal [34].

Three cortical modules activate and communicate to implement reappraisal (Fig. 1) [62,72]. The first of these modules is comprised of the dorsolateral prefrontal cortex (dlPFC) and posterior parietal cortex (PPC). dlPFC and PPC form the “dorsal attention system”, which exerts top-down, volitional control over attention and working memory processes [18,20,75,89,109]. In the context of reappraisal, dlPFC sends output to other prefrontal and PPC regions, helping to direct attention

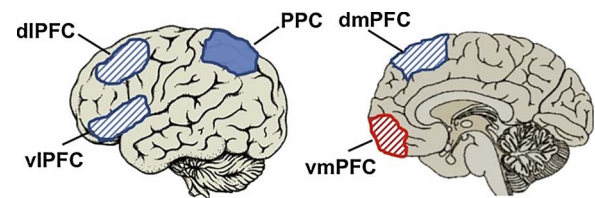


Fig. 1. Neural systems underlying emotion regulation capacity and tendency. Regions marked in blue (dlPFC; dmPFC; PPC; vIPFC) signify areas associated with the capacity to reappraise while red (vmPFC) indicates regions associated with reduced negative affect when responding to aversive stimuli. Hashed regions indicate brain areas associated with trait tendencies to self-regulate.

Note: dlPFC refers to dorsolateral prefrontal cortex; PPC refers to posterior parietal cortex; vIPFC refers to ventrolateral prefrontal cortex; dmPFC refers to dorsomedial prefrontal cortex. Depictions were created using conventional, functional anatomical knowledge and are meant to be taken as schematic.

and select reappraisals from working memory [12,24,62,99]. In addition to controlling attention [19,74], PPC supports perspective taking and spatial processing [47,104]. PPC is strongly recruited by forms of reappraisal that involve emotional distancing [79], suggesting that it regulates perceptions of an emotional stimulus’s relevance or proximity [80,82]. The second module is the ventrolateral prefrontal cortex (vIPFC), which co-activates with dlPFC and PPC to coordinate complex cognitive control processes as well as reappraisal [5,12,14,24,37,57,86,87,94]. vIPFC allows one to choose and inhibit cognitions and actions in accordance with goals, and appears important for selecting and implementing reappraisals [18,75,82,99,112]. Given the linguistic nature of some reappraisal tactics (i.e., constructing an alternative narrative for an emotional stimulus), vIPFC activation might also reflect engagement of language processing during reappraisal [49,61,82]. Importantly, functional connectivity has been observed between vIPFC and the amygdala, but not other lateral prefrontal regions – suggesting that vIPFC serves as the ultimate modulatory output of prefrontal and parietal systems acting on the amygdala [73,102]. The final module implicated in reappraisal capacity is dmPFC. While anterior portions of dmPFC support mentalizing and other social cognitions, posterior dmPFC and adjacent cingulate regions are critical for monitoring goal-directed behavior [1,23,27,28,76,83]. Therefore, anterior and posterior dmPFC may respectively evaluate one’s affective state and the degree to which one is staying on task during reappraisal.

Neuroimaging meta-analytic data have revealed that reappraisal recruits dlPFC, PPC, vIPFC and dmPFC, and diminishes amygdala activity [12,24]. Preliminary evidence suggests that dlPFC instigates reappraisal-related activity, which subsequently excites vIPFC and dorsomedial regions like the dorsal anterior cingulate cortex (dACC) and supplementary motor area [62,72]. By contrast, vIPFC appears to inhibit dlPFC during reappraisal in a manner that is suggestive of a self-regulating feedback loop [72]. Though such findings elucidate the nature of cortical–cortical interactions during reappraisal, it remains less clear how cortical-subcortical communication is instantiated. Prefrontal and parietal activity are inversely associated with amygdala recruitment during reappraisal [77,102,110], but it is unknown how regions like dlPFC might attenuate amygdala activity given scarce direct connections between them [36,37]. One possibility is that prefrontal and parietal “source regions” alter semantic representations of affective stimuli in posterior temporal regions, which in turn down-regulate the amygdala [12]. However, this hypothesis remains untested. A second possibility is that dlPFC and vIPFC act on vmPFC regions involved in “implicit” regulatory processes like fear extinction, which subsequently reduce amygdala activity [24,52,93,107]. This notion is appealing given that vmPFC, in particular regions close to the genu, has dense connections with the amygdala [8,15]. While little work has investigated functional connectivity during reappraisal, preliminary studies have reported vmPFC-amygdala coupling during reappraisal [4,100]. At the same time, a large meta-analysis of reappraisal

studies failed to find evidence for vmPFC recruitment during reappraisal, leaving open questions about the plausibility of this pathway [12]. A final possibility is that reappraisal-related activation in lateral prefrontal and posterior parietal regions alter amygdala activation via dACC [62]. The evidence for this pathway is threefold: (1) it is supported by the sole effective connectivity study of reappraisal to date [62], (2) dACC has rich connections with the amygdala [37], and (3) dACC recruitment predicts reappraisal-related decreases in negative affect, suggesting it may target affective signals generated by the amygdala [77].

2.3. Emotion regulation tendency

While the bulk of neuroimaging research on emotion regulation has focused on capacity, it is equally important to consider an individual's *tendency* to utilize specific regulatory strategies [25,42,79]. Here, we define tendency as one's inclination to utilize particular emotion regulation strategies. As in prior sections, we will focus primarily on reappraisal but because few neuroimaging studies have looked at emotion regulation tendency of any kind, we will discuss non-reappraisal research as well. In the following section, we describe two approaches to examining regulatory tendency. The first approach involves examining stable, trait-like, person-level tendencies to use specific regulatory strategies like reappraisal. The second approach, involves examining how situational variables dynamically impact regulatory choices from one context to another. Characterizing regulatory tendency in terms of both person-level and situation-level factors enriches our emotion regulation framework and moves it beyond more traditional individual difference measures of emotion regulation.

2.3.1. Person-level variables involved in emotion regulation tendency

One approach to studying person-level *trait* regulatory tendencies is to collect self-report measures and correlate these data with brain function. For example, one study found that individuals who frequently reappraise in everyday life strongly recruit prefrontal control regions involved in reappraisal (vlPFC, dlPFC, dmPFC) and attenuate amygdala activity when presented with emotional stimuli [29]. Another study found that trait tendencies to exhibit more regulated behavior – though it was unclear what strategies participants used in order to regulate – were associated with greater decreases in negative affect, stronger attenuation of the amygdala response, and stronger amygdala connectivity with vlPFC and dmPFC during reappraisal [85]. This indicates that the tendency to self-regulate predicts recruitment in brain regions that support the capacity to reappraise [84,106]. However, additional work is needed to determine whether such activation reflects regulation-related decision making, active reappraisal, or the engagement of reappraisal-like brain networks being used in the service of alternative cognitive strategies (for example, distraction recruits similar circuits to reappraisal).

Another approach to studying emotion regulation tendencies has been to correlate brain activity or connectivity during uninstructed responding to emotional stimuli with self-reported affective *states*. The logic here is that if brain activation tracks with reduced negative affect, such activation likely reflects emotion regulation. In contrast to prior approaches discussed, this approach does not focus on specific regulatory strategies (e.g., reappraisal) or explicit endorsement of self-regulation. This approach gives unimpeded access to what neural processes give rise to more or less negative affect, but fails to tell us what participants are doing *psychologically* nor does it preclude the possibility that brain activation reflects reduced emotional reactivity rather than regulation. Broadly, this work has linked greater vmPFC recruitment and diminished amygdala activation to less negative appraisals of aversive stimuli [30,54,66,103,108]. Such results suggest that when left to their own devices, individuals tend to engage in implicit forms of emotion regulation – which are perhaps sculpted by basic feedback mechanisms – and are undergirded by vmPFC [11,32,45].

2.3.2. Situation-level variables involved in emotion regulation tendency

Behavioral research suggests that contextual factors influence regulatory tendencies [98]. For example, individuals choose to reappraise rather than self-distract when faced with low-intensity emotional stimuli and vice versa for high-intensity emotional stimuli [95,97]. This suggests that individuals compute a cost-benefit analysis to determine whether it is worth exerting the cognitive resources – for example, engaging working memory [32] – required to reappraise high-intensity affective stimuli [98]. While event-related potential data support the notion that neural computations of a stimulus's emotional intensity predict regulatory strategy choice, the limited spatial resolution associated with EEG makes it difficult to say what neural circuits support regulatory decisions and implementations [96]. As such, complementary neuroimaging methods are needed to better characterize the neural bases of situational influences on emotion regulation tendencies.

3. Synthesis and future directions

3.1. Mutual reinforcement of regulation capacity and tendency in lateral prefrontal and parietal systems

The extant literature demonstrates that reappraisal capacity is supported by interactions between dlPFC, vlPFC, dmPFC, PPC and the amygdala [12,82]. Critically, neural responses to affective stimuli in these same brain regions predicts the tendency to reappraise [26,29]. This raises the question of how closely linked individual differences associated with capacity and tendency are. One unexplored possibility is that the strength of association between capacity and tendency changes during development. Given that experience shapes neural circuits during childhood and adolescence, it is likely that neural pathways involved in emotion regulation are shaped by Hebbian-like loops of plasticity during development (i.e., the tendency to use reappraisal builds capacity and vice versa) [35]. Thus, one might predict that capacity and tendency are tightly linked during childhood and adolescence when emotion regulation abilities are changing most dramatically [101]. However, once an individual reaches adulthood and achieves regulatory proficiency, it is less clear whether tendency and capacity ought to remain coupled. For example, tendency and capacity might become uncoupled with age if one is capable of deploying multiple regulatory strategies but uses just one strategy, resulting in high capacity but low tendency for the unused strategies. Alternatively, an adult might employ a strategy that they are not skilled at using because cultural norms encourage its use, whereas a child might be less sensitive to such norms. Indeed, several studies have failed to find strong relationships between reappraisal capacity and tendency [38,69,105], and this may explain why adults with psychopathology often display normal regulation capacity while experiencing functional impairments (i.e., capacity is intact while tendency is not) [31,39,56]. Such possibilities raise intriguing questions about how emotion regulation matures and how interventions might be best implemented across development [7,71].

3.2. Conclusions

Here we have presented a preliminary framework for how regulatory capacity and tendency jointly contribute to emotion regulation. Together, these advances stand to enhance basic, developmental, and translational knowledge about how prefrontal and subcortical systems dynamically interact to support emotion regulation and associated wellbeing.

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